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(54) **Encapsulated light emitting diode and method for encapsulating the same.**

(57) Encapsulation of semiconductor light emitting diodes (40), in particular laser diodes, characterized in that a gap (47) is formed in an encapsulant (45), which is situated in front of the light emitting facet of the diode (40), said gap preventing the encapsulant (45) from adhering to this facet.

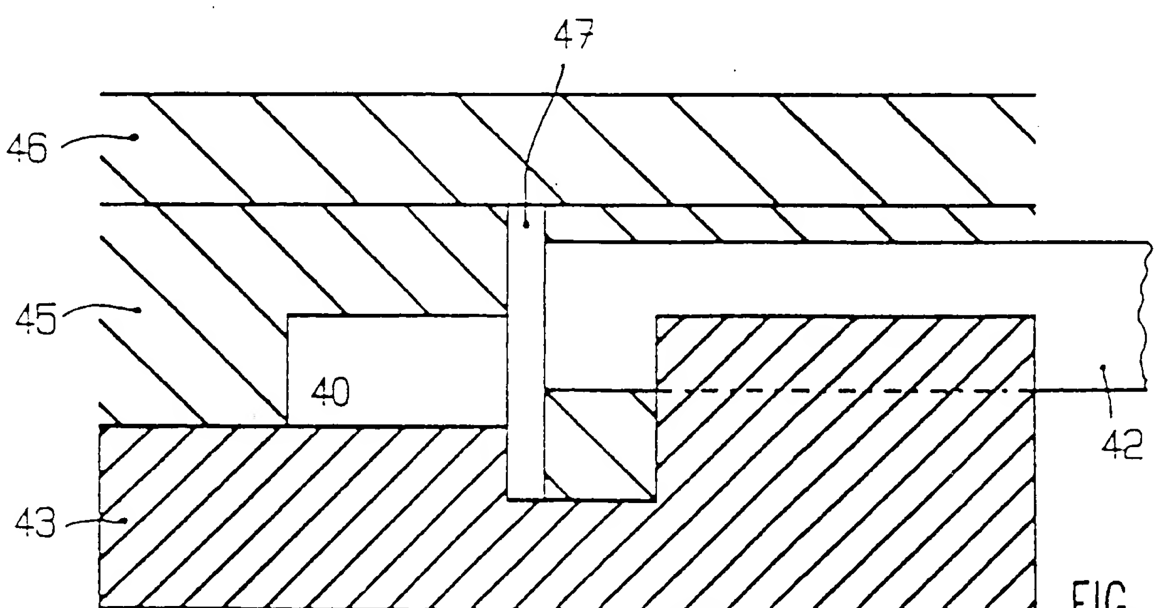

FIG. 4C

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TECHNICAL FIELD

The invention describes a means for hermetically sealing light emitting diodes, in particular laser diodes, to yield protection from the environment and to simplify packaging.

BACKGROUND OF THE INVENTION

Semiconductor light emitting diodes, being very sensitive against moisture, exposure to chemicals such as detergents, and mechanical stress and strain, have to be encapsulated, in and protected by, an appropriate housing. Additionally, the housing should allow electrical as well as optical interconnections.

Encapsulation and packaging of these diodes should be simple and cheap on one hand and as reliable and durable as possible on the other hand. Different means for encapsulation of conventional semiconductor devices are known in the art, most of them not being suited for application to light emitting diodes, or being mechanically complex. However, some proposals are known, reducing the complexity of the housing as such and employing epoxy-like materials for hermetically sealing a diode.

One example, out of a wide variety of similar proposals, is given in European Patent application, EP-A 0 466 975, with title "Semiconductor Light-Emitting Device". The principle of the light emitting device's encapsulation is schematically illustrated in Figure 1. As can be seen in this Figure, an edge emitting laser diode 10 is mounted on a mounting base 11. In a certain distance to this diode 10, a cube 12 with 45 ° mirror facet 13 is situated, providing for an optical output port. The laser diode 10 and the already mentioned cube 12 are sealed and held in a transparent resin 14. This resin 14 adheres to the laser's facets and fills the space between the laser 10 and the cube 12. The upper surface of the cube 12 is not covered by the resin 14. As indicated by arrow 15, a light beam emitted from the laser 10 propagates through the resin 14, prior to being reflected out of the resin 14.

A critical element of a light emitting diode is the light emitting facet, referred to as mirror facets when addressing laser diodes. Because of the small emitting area, depending on the design of a light emitting diode, the optical flux density can become very high (> 1 MW/cm^2) and consequently corrosion or contamination can easily lead to degradation of the output or melting of the light emitting facet through thermal runaway. Organic encapsulants, such as the transparent resin employed in Figure 1, all have very low thermal conductivity so that only a small degree of absorption can result in a high local temperature rise. For this reason, most of the laser diodes are hermetically sealed in metal enclosures which ensure that only an inert gas is in contact with the sensitive facets. An important disadvantage of hermetically sealing light emitting diodes using an encapsulant, as for example shown in Figure 1, is that the encapsulant adheres to the light emitting facet thus directly interacting with it and causing thermal problems if light beams with high optical flux density are generated. Furthermore, chemical changes in the encapsulant, caused by the high optical flux, can accelerate degradation (corrosion) of the facet.

OBJECTS OF THE INVENTION

It is an object of the present invention to provide for a hermetic encapsulation of light emitting diodes which overcomes the disadvantages of known encapsulations.

It is another object of the present invention to provide for a simple, reliable and low cost encapsulation technique.

SUMMARY OF THE INVENTION

This has been accomplished by providing for an 'air' gap, or a region having an inert gas in direct contact with the light emitting facet of a light emitting diode, the remaining portions of the diode being sealed in an encapsulant.

DESCRIPTION OF THE DRAWINGS

The invention is described in detail below with reference to the following drawings, which are schematic and not drawn to scale, while more particularly the dimensions of some parts are exaggerated for the sake of clarity.

FIG. 1 shows a schematic cross-section of an edge emitting laser diode and an optical output port sealed in a transparent resin, as known in the art.

FIG. 2 shows a schematic cross-section of an edge emitting laser diode encapsulated with the provision of an 'air' gap in front of the mirror facet, according to the first embodiment of the present invention.

FIG. 3 shows steps of the encapsulation of an edge emitting laser diode, in accordance with the first embodiment of the present invention:

A bonding the laser diode to a mounting base and placing a thin foil in front of the mirror;

B sealing the laser diode, the thin foil serving as a dam;

C removing the foil and covering the whole structure with an encapsulant.

FIG. 4 shows steps of the encapsulation of an edge emitting laser diode and an optical fiber, in accordance with the second embodiment of the present invention:

A bonding the laser diode to a mounting base and placing an optical fiber in a groove;

B placing a thin foil in front of the mirror of the laser diode and pushing the fiber against it;

C removing the foil and covering the whole structure with an encapsulant to seal the structure.

FIG. 5 shows steps of the encapsulation of an edge emitting laser diode and an optical lens, in accordance with the third embodiment of the present invention:

A mounting the laser diode on a mounting base;

B placing a thin foil in front of the mirror of the laser, covering the structure with a sealing cap and inserting a lens;

C turning the whole structure and partially filling it with an encapsulant;

D removing the foil and filling the sealing cap up with an encapsulant.

GENERAL DESCRIPTION

Before describing different embodiments of the present invention, some different materials to be employed as encapsulants are described separately. These materials, which have to be transparent when being situated in the light path and in addition should be durable and easy to handle, are well known in the art. Typical materials are cyclic alipathic epoxy resins, diglycidyl esters, polyurethans, and polymethyl methacrylates (PMMA), to name some of them. Different diglycidyl esters are described in the European Patent EP-B 0 039 017, with title "Verfahren zur Herstellung transparenter Giessharze". Additional information is available from manufactures of optical resins or their distributors. A listing of some resins is for example given in a leaflet, published by Polyscience AG, Bleichistrasse 8, CH-6300 Zug/Switzerland, titled "UV-aushärtende Epoxies, Klebstoffe und Abdeckmassen". Said Polyscience AG is a distributor of products of the Electro-Lite Corporation, Danbury, CT, U.S.A..

A first embodiment of the present invention is described in Figure 2. In this Figure, a schematic cross-section through a module comprising an edge emitting laser diode 20, its active layer being indicated by dashed line 21, situated on, and bonded to, a mounting base 23 is illustrated. The whole laser diode 20 is encapsulated by a transparent resin 24 providing for a narrow 'air' gap 27 in front of, and in direct contact to, the laser's mirror 22. The width of said 'air' gap is typically less than 1000 μm., and preferably between 5 μm and 100 μm. The hermetically sealed gap 27 ensures an environment of optimum conditions being decoupled from the surrounding environment. The laser mirror 22 is not exposed to mechanical stress/strain or chemicals, after being encapsulated. Further packaging of this diode, being encapsulated in accordance with the present invention, can be done by employing conventional metal housings with window, as f.e. given in US Patent US-A 5 052 009, with title "Semiconductor Laser Device and Process of Assembling the Same".

The method for encapsulating the laser diode 20 is explained in context with Figures 3A - 3C, which show intermediate steps of the encapsulation. As shown in Figure 3A, a laser diode 20 is mounted junction-side-up, also referred to as epi-side-up, on top of a mounting base 23. The laser diode 20 may be bonded to this mounting base 23, f.e.. A thin foil 28, of well defined thickness w, is placed and fixed in front of the mirror facet of the laser 20. This foil 28 has to be held in place during the next step by means of clamps for example. Next, the laser diode 20 and the foil 28 are sealed in a first encapsulant 29. This encapsulant 29 should be transparent for the particular wavelength emitted by the laser, such that a light beam emitted can pass through the encapsulant 29 nearly unattenuated. As shown in Figure 3B, the upper portion of the foil 28 remains uncovered, the foil serving as kind of a dam. Prior to finally encapsulating the whole structure, the foil 28 has to be removed after the first encapsulant has hardened. This can either be done by etching it, solving it in a suitable solvent, or by mechanically removing it. After removal of the foil 28, a narrow gap 27 is left in direct contact to the mirror, the width of the gap 27 being defined by the foil's thickness w. To complete the encapsulation, a further layer of an encapsulant 30 is laid over the structure covering up the gap 27, as shown in Figure 3C. The trapped air or inert gas, e.g. nitrogen, in the gap 27 prevents ingress of this additional layer 30. Choosing an encapsulant of high viscosity and a narrow width of the gap, the whole process can be carried out in a vacuum environment, such that there is a vacuum in said gap 27. Rapid application and accelerated

hardening, e.g. by employment of bin UV-light source, ensures that the encapsulant is not drawn into the gap.

By the means described in context with the first embodiment, the laser is completely sealed but no epoxy or other encapsulant comes in contact with the laser mirror. However, in this particular embodiment, an encapsulant is present in the optical light path. As can be seen in Figures 4A - 4C, there are other embodiments, eliminating the encapsulant from the optical path.

The second embodiment, described in connection with Figures 4A - 4C, concerns an edge emitting laser diode 40 being coupled to an optical fiber 42 serving as optical output port. As illustrated in Figure 4A, said laser 40 is mounted junction-side-up, the dashed line representing the active layer 41, on top of a structured mounting base 43. This mounting base 43 is structured such that it provides for a mounting area to which said laser 40 can be bonded, an alignment support for the fiber 42, which either is part of said mounting base 43 or attached to it. A recess may be situated between the laser's mounting area and the alignment support, if necessary. Said alignment support is shaped such that the fiber has only one degree of freedom, i.e. perpendicular to the plane of the laser mirror. This can be achieved by provision of a v-shaped groove in said alignment support, as known from articles such as "Self-Adjusted Permanent Attachment of Fibers to GaAs Waveguide Components", H. Kaufmann et al., Electronics Letters, Vol. 22, No. 12, June 1986, pp. 642 - 643.

Next, a thin foil 44 is placed between the mirror and the fiber 42, with the latter being used to clamp the foil 44 gently against the surface of the mirror by pushing the fiber 42 towards the laser 40, as indicated by the arrow on the right hand side of Figure 4B. Similar to the first step of encapsulation, described in context with the first embodiment, an encapsulant 45 is flowed over the laser 40 and fiber 42 with the foil 44 acting as a dam. This intermediate step is schematically shown in Figure 4B. After this encapsulant 45 has hardened, the foil 44 is removed using suitable means as already described. A narrow gap 47 is left between the laser mirror and the fiber 42 - of width defined by the foil thickness. The encapsulation is completed by application of a further encapsulation layer 46. As can be seen in Figure 4C, the complete laser is covered, no encapsulant remaining in the optical path. Efficient optical coupling is ensured by this technique. The alignment between the fiber 42 and the laser 40 is highly reproducible and precise.

The third embodiment of the present invention is pointed out in connection with Figures 5A through 5D. As can be seen from these Figures, the complete packaging of a laser diode 50 will be described. Prior to starting with the encapsulation of laser diode 50, it has to be bonded to a substrate 51. This substrate 51 is fixed at, or connected to, a base plate 52 with metal pins 53. The upper ends of these metal pins 53 are connected by means of connecting wires 54 to the laser's contact metallizations, not shown in the Figures. Next, a thin soluble foil 55 is placed on top of the front mirror of the laser 50 such that it covers at least the light emitting portion thereof. A cylindrical sealing cap 56, preferably made of metal, which has a window in its upper portion is situated on top of the baseplate 52. An optical lens 57, e.g. being shaped like a mushroom, is inserted from outside of the sealing cap in said window, the size of said window and said lens being chosen such that the lens 57 can be moved up and down. By pressing the lens 57 against the foil 55, it is clamped in place. As shown in Figure 5C, the whole structure will now be turned 90 °. Similar to the steps already described in context with the first and second embodiment, an encapsulant 58 is now flowed over the laser 50, mounted on the substrate 51, the foil 55, and the lens 57. This liquid encapsulant is poured into the inner portion of the sealing cap 56 via an opening 59, f.e.. After this encapsulant 58 has hardened, either the sealing cap 56 is removed to bring the foil 55 in contact with a suitable solvent, or this solvent is directly filled into the sealing cap using opening 59. After this step, a narrow gap is left between the laser mirror and the lens 57. The remaining portion of the sealing cap 56, back in its original position, is now filled up with an encapsulant 61. It should be ensured that the gap 60 is not filled with this encapsulant 61.

It should be obvious, that the different embodiments described above can be modified without deviating from the gist of the invention. Some exemplary modifications are mentioned below:

- various kinds of light emitting diodes, such as surface emitting diodes, arrays of laser diodes and so forth, can be encapsulated in accordance with the present invention;
- The shape, size, thickness, and material of the foil, to be placed in front of the light emitting facet, can be chosen to be well suited for the respective environment;
- the light emitting diode can either be mounted epi-side-up or -down, which ever allows better packaging and cooling:
- the mounting base and fiber alignment support can be modified if necessary;
- conventional baseplates and sealing caps, as well as specially designed ones, can be employed;
- Multi mode fibers, single mode fibers, fiber arrays, rod lenses, focusing or spreading len-

ses, simple plane windows or other optical means, such as beam splitters can be coupled to, and encapsulated with, a light emitting diode, in accordance with the present invention.

By the above described means, light emitting diodes are completely sealed, but no encapsulant comes in contact with their light emitting facets. To summarize, the described packaging technique makes possible the use of a wide variety of different encapsulants. The resultant reduction in complexity and cost on one hand, combined with increased device lifetime and improved reliability, extends the range of applications of these devices.

Claims

1. Optical module comprising a semiconductor light emitting diode (20; 40; 50) mounted on a mounting base (23; 43; 51), at least one optical output port (42; 57), and an encapsulant (24; 45, 46; 58, 61) sealing said diode (20; 40; 50) and holding it in place, characterized in that a narrow gap (27; 47; 60), situated in front of the light emitting facet of said diode (20; 40; 50), is formed in said encapsulant (24; 45, 46; 58, 61) such that the encapsulant (24; 45, 46; 58, 61) does not adhere to the light emitting portion of said light emitting facet, providing for an optical path starting at said light emitting portion, passing through said gap (27; 47; 60) and leaving the module via said optical output port (42; 57).

2. The optical module of claim 1, characterized in that light emitting diode is a laser diode (20), the light emitting facet (22) thereof being one of the facets defining the cavity of the laser (20).

3. The optical module of claims 1 or 2, characterized in that said narrow gap (27; 47; 60) has a width between 5 µm and 100 µm.

4. The optical module of claim 1, characterized in that an optical fiber (42) serves as optical output port, this fiber being aligned with respect to the light emitting portion of the diode such that the optical path starts at said light emitting portion, passes through said gap (47) directly into said optical fiber (42) and leaves the module via said fiber (42).

5. The optical module of claim 4, characterized in that said fiber (42) is pre-aligned in an alignment support having a v-shaped groove, its main axis being approximately perpendicular to the light emitting facet of the diode (40), said alignment support being part of, or being attached to, said mounting base (43).

6. The optical module of claim 1, characterized in that an optical lens (57) serves as optical output port, this lens (57) being aligned with respect to the light emitting portion of the diode (60) such that the optical path starts at said light emitting portion, passes through said gap (60) directly into said optical lens (57) and leaves the module via said lens (57).

7. The optical module of claim 6, characterized in that said lens (57) is situated in a window of a sealing cap (56), the mounting base (51) of the light emitting diode (50) being fixed at a baseplate (52), said sealing cap (56) covering the diode (50) and the mounting base (51), such that the position of said lens (57) with respect to the light emitting portion of the diode (50) is automatically defined.

8. The optical module of claim 1, characterized in that said encapsulant (24; 45, 46; 60, 61) comprises cyclic alipathic epoxy resin, diglycidyl ester, polyurethan, or polymethyl methacrylate (PMMA).

9. The optical module of claim 1, characterized in that vacuum conditions are established in said gap (27; 47; 60), or that said gap (27; 47; 60) is filled with an inert gas, such as nitrogen.

10. Method for the encapsulation of a semiconductor light emitting diode (20; 40; 50), comprising the steps of:
    a) mounting said diode (20; 40; 50) on a mounting base (23; 43; 51),
    b) placing a thin foil (28; 44; 55) in front of the light emitting facet of said diode (20; 40; 50), said foil (28; 44; 55) covering at least the light emitting portion of said light emitting facet,
    c) flowing a first encapsulant (29; 45; 58) over the diode (20; 40; 50) with the foil (28; 44; 55) acting as dam;
    d) removing said foil (28; 44; 55) after said first encapsulant (29; 45; 58) has hardened, leaving a narrow gap (27; 47; 60) in direct contact with said light emitting facet,
    e) completing the encapsulation by flowing a second encapsulant (30; 46; 61) over said structure such that the second encapsulant (30; 46; 61) covers the opening of the gap (27; 47; 60) but is not drawn into it.

11. Method of claim 10, characterized in that said foil (28; 44; 55) is a soluble foil, said foil (28;

44; 55) being removed by employment of a suitable solvent.

12. Method of claim 10, characterized in that an optical fiber (42) is placed in an alignment support and pressed against said foil (44) prior to step c), the fiber (42) serving as clamp.

13. Method of claim 10, characterized in that said first encapsulant (29; 45; 58) and/or second encapsulant (30; 46; 61) comprise(s) cyclic alipathic epoxy resin, diglycidyl ester, polyurethan, or polymethyl methacrylate (PMMA).

14. Method of claim 11, characterized in that step e) is carried out in a well defined environment such as an inert gas atmosphere, e.g. nitrogen, or in a vacuum.

Amended claims in accordance with Rule 86-(2) EPC.

1. Optical module comprising a semiconductor light emitting diode (20; 40; 50) mounted on a mounting base (23; 43; 51), and an encapsulant (24; 45, 46; 58, 61) sealing said diode (20; 40; 50), characterized in that a gap (27; 47; 60), is provided in front of the light emitting portion of said diode's (20; 40; 50) light emitting facet such that at least said light emitting portion is placed in a defined atmosphere.

2. The optical module of claim 1 comprising at least one optical output port (42; 57) being placed such that said gap (27; 47; 60) is situated between the light emitting portion of said light emitting facet and said optical output port (42; 57) in order to provide an optical path starting at said light emitting portion, passing through said gap (27; 47; 60) and leaving the module via said optical output port (42; 57).

3. The optical module of claim 1 or 2, characterized in that said light emitting diode is a laser diode (20), the light emitting facet (22) thereof being one of the facets defining the cavity of the laser (20).

4. The optical module of claim 1, 2, or 3, characterized in that said gap (27; 47; 60) has a width between 5 µm and 100 µm.

5. The optical module of claim 2, characterized in that an optical fiber (42) serves as optical output port, this fiber being aligned with respect to the light emitting portion of the diode such that the optical path starts at said light emitting portion, passes through said gap (47) directly into said optical fiber (42) and leaves the module via said fiber (42).

6. The optical module of claim 5, characterized in that said fiber (42) is pre-aligned in an alignment support having a v-shaped groove, its main axis being approximately perpendicular to the light emitting facet of the diode (40), said alignment support being part of, or being attached to, said mounting base (43).

7. The optical module of claim 2, characterized in that an optical lens (57) serves as optical output port, this lens (57) being aligned with respect to the light emitting portion of the diode (60) such that the optical path starts at said light emitting portion, passes through said gap (60) directly into said optical lens (57) and leaves the module via said lens (57).

8. The optical module of claim 7, characterized in that said lens (57) is situated in a window of a sealing cap (56), the mounting base (51) of the light emitting diode (50) being fixed at a baseplate (52), said sealing cap (56) covering the diode (50) and the mounting base (51), such that the position of said lens (57) with respect to the light emitting portion of the diode (50) is automatically defined.

9. The optical module of claim 1 or 2, characterized in that said encapsulant (24; 45, 46; 60, 61) comprises cyclic alipathic epoxy resin, diglycidyl ester, polyurethan, or polymethyl methacrylate (PMMA).

10. The optical module of claim 1 or 2, characterized in that vacuum conditions are established in said gap (27; 47; 60).

11. The optical module of claim 1 or 2, characterized in that said gap (27; 47; 60) is filled with an inert gas, such as nitrogen.

12. The optical module of claim 1 or 2, characterized in that said gap (27; 47; 60) is filled with air.

13. Method for the encapsulation of a semiconductor light emitting diode (20; 40; 50), comprising the steps of:
 a) mounting said diode (20; 40; 50) on a mounting base (23; 43; 51),
 b) placing a thin foil (28; 44; 55) in front of the light emitting facet of said diode (20; 40; 50), said foil (28; 44; 55) covering at least the light emitting portion of said light emit-

ting facet,

c) flowing a first encapsulant (29; 45; 58) over the diode (20; 40; 50) with the foil (28; 44; 55) acting as dam;

d) removing said foil (28; 44; 55) after said first encapsulant (29; 45; 58) has hardened, leaving a gap (27; 47; 60) in direct contact with the light emitting portion of said light emitting facet,

e) completing the encapsulation by flowing a second encapsulant (30; 46; 61) over said structure such that the second encapsulant (30; 46; 61) covers the opening of the gap (27; 47; 60) but is not drawn into it.

14. Method of claim 13, characterized in that said foil (28; 44; 55) is a soluble foil, said foil (28; 44; 55) being removed by employment of a suitable solvent.

15. Method of claim 13, characterized in that an optical fiber (42) is placed in an alignment support and pressed against said foil (44) prior to step c), the fiber (42) serving as clamp.

16. Method of claim 13, characterized in that said first encapsulant (29; 45; 58) and/or second encapsulant (30; 46; 61) comprise(s) cyclic alipathic epoxy resin, diglycidyl ester, polyurethan, or polymethyl methacrylate (PMMA).

17. Method of claim 14, characterized in that step e) is carried out in a well defined environment such as an inert gas atmosphere, e.g. nitrogen, or in a vacuum.

18. Method of claim 14, characterized in that step e) is carried out in air.

European Patent Office

EUROPEAN SEARCH REPORT

Application Number

EP 92 81 0786

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DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
D,A	EP-A-0 466 975 (MITSUBISHI DENKI KABUSHIKI KAISHA) * the whole document * ---	1-6,8,10	H01S3/025 H01L33/00 G02B6/42
A	PATENT ABSTRACTS OF JAPAN vol. 9, no. 126 (E-318)31 May 1985 & JP-A-60 12 782 (SUMITOMO DENKI KOGYO KK) * abstract * ---	1,10	
A	EP-A-0 374 121 (RSF ELEKTRONIK GMBH) * the whole document * ---	1,10	
A	PATENT ABSTRACTS OF JAPAN vol. 12, no. 389 (E-669)17 October 1988 & JP-A-63 131 586 (TOSHIBA CORP) * abstract * ---	1,10	
A	PATENT ABSTRACTS OF JAPAN vol. 13, no. 51 (E-712)6 February 1989 & JP-A-63 244 781 (FURUKAWA ELECTRIC CO LTD) * abstract * ---	1,10	TECHNICAL FIELDS SEARCHED (Int. Cl.5)
A	PATENT ABSTRACTS OF JAPAN vol. 6, no. 21 (E-93)6 February 1982 & JP-A-56 142 657 (NIPPON DENKI KK) * abstract * ---	1,10	H01S H01L G02B
A	PATENT ABSTRACTS OF JAPAN vol. 10, no. 69 (E-389)18 March 1986 & JP-A-60 217 687 (HITACHI SEISAKUSJO KK) * abstract * ---	1,2, 10-12	
D,A	EP-A-0 039 017 (SIEMENS) * the whole document * -----	1,8,10, 13	

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	25 JUNE 1993	CLAESSEN L.M.

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

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EUROPEAN SEARCH REPORT

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DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
			TECHNICAL FIELDS SEARCHED (Int. Cl.5)
	The present search report has been drawn up for all claims		

Place of search	Date of completion of the search	Examiner
THE HAGUE	25 JUNE 1993	CLAESSEN L.M.

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D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

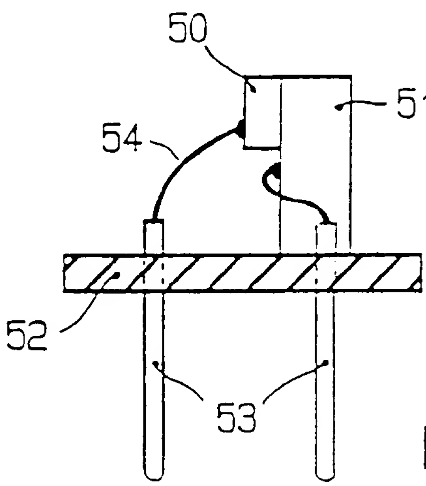

FIG. 5A

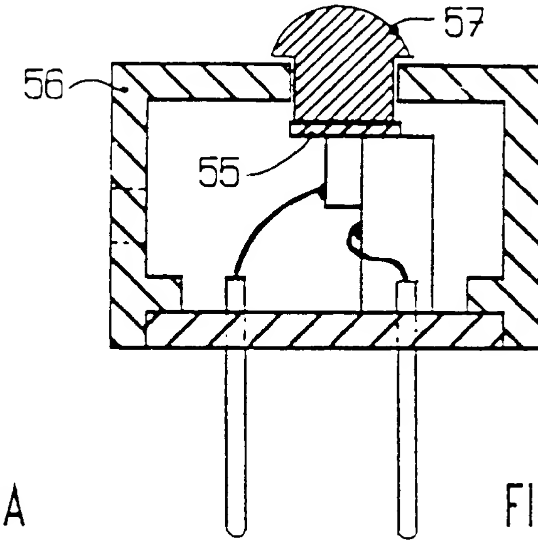

FIG. 5B

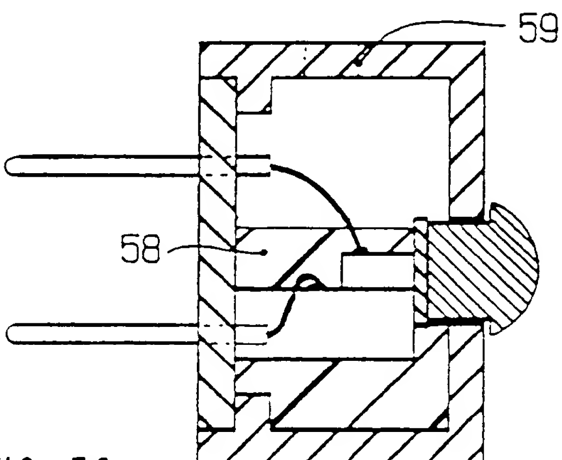

FIG. 5C

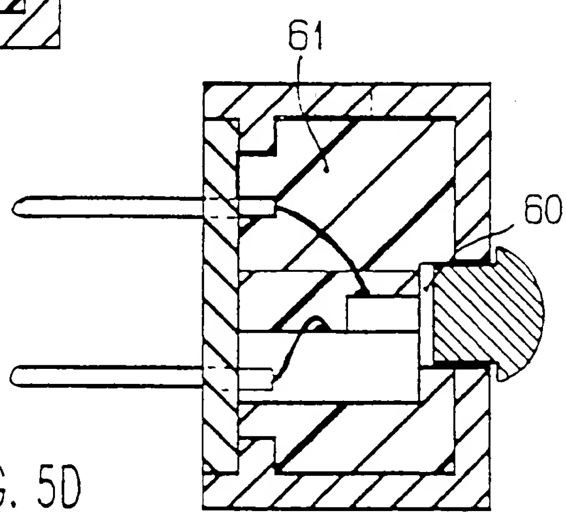

FIG. 5D

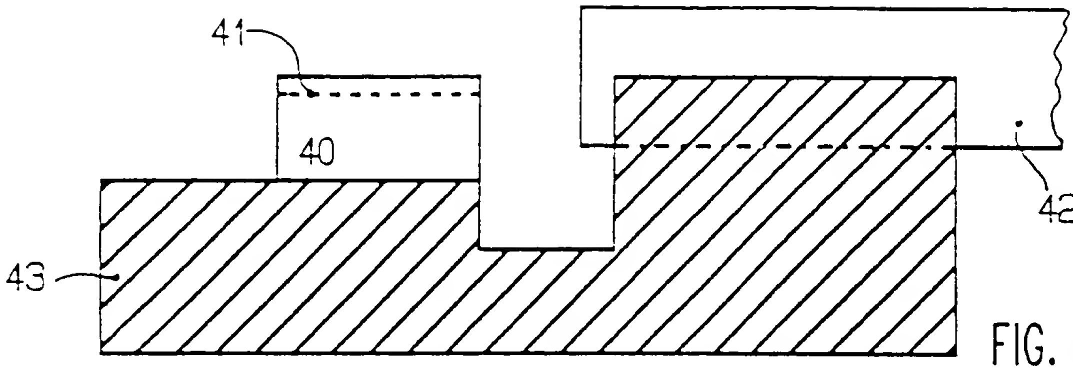

FIG. 4A

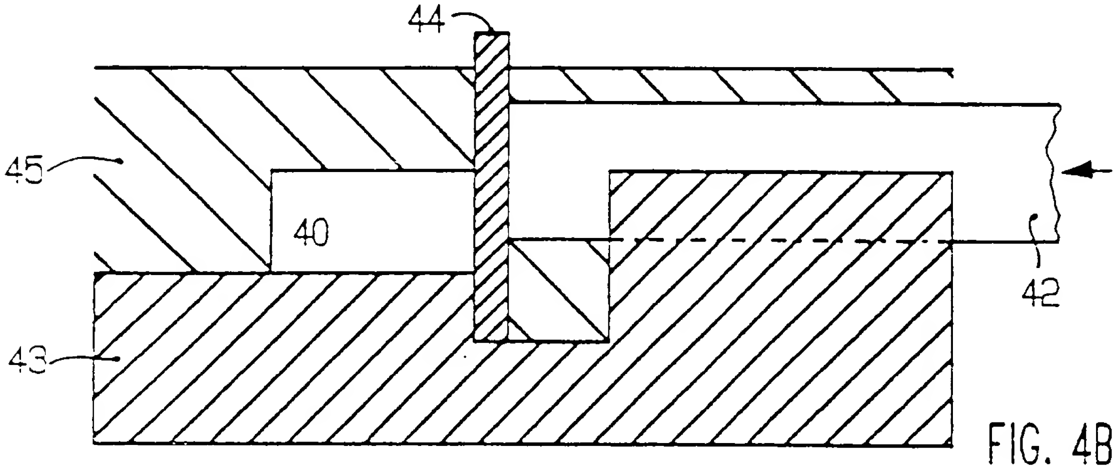

FIG. 4B

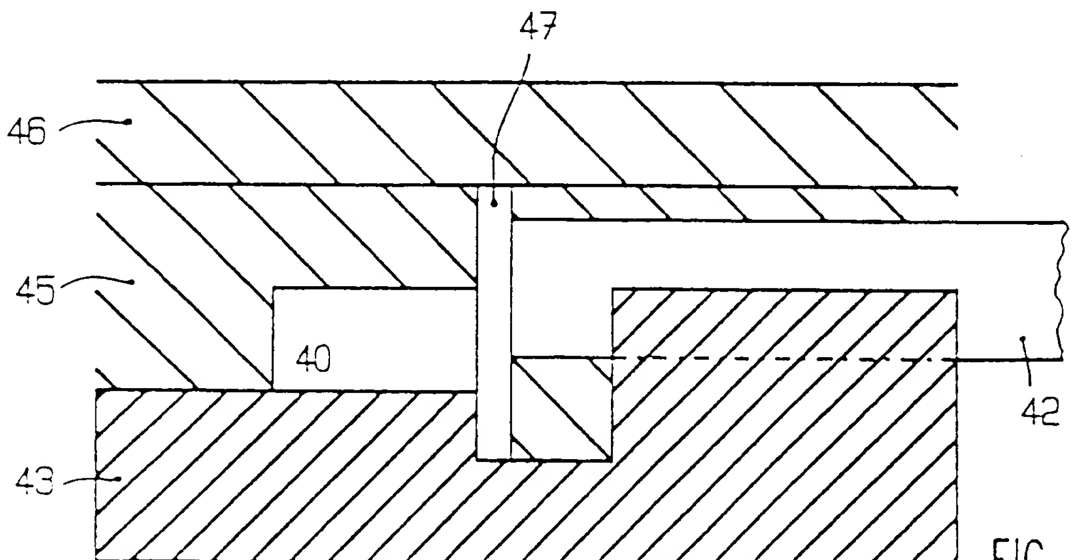

FIG. 4C

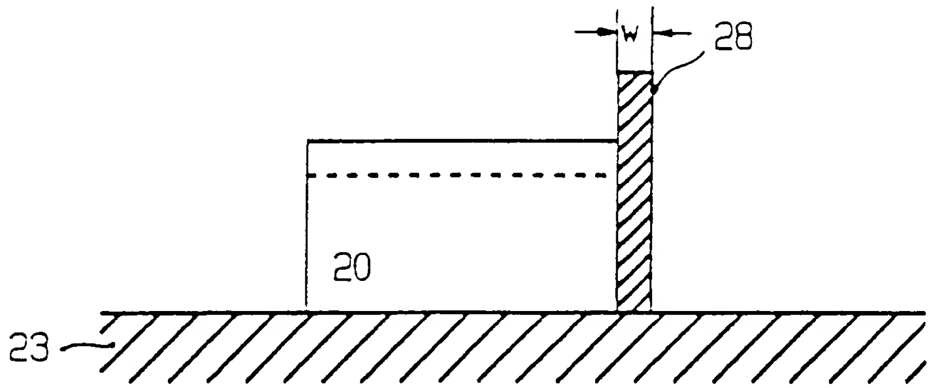

FIG. 3A

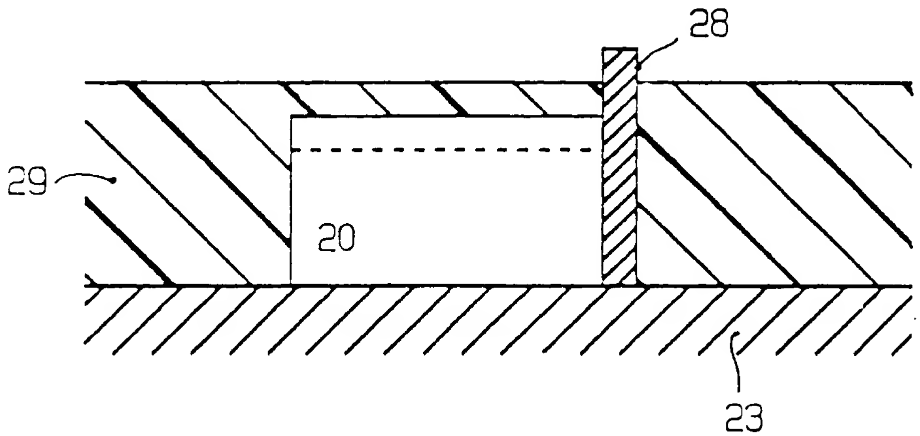

FIG. 3B

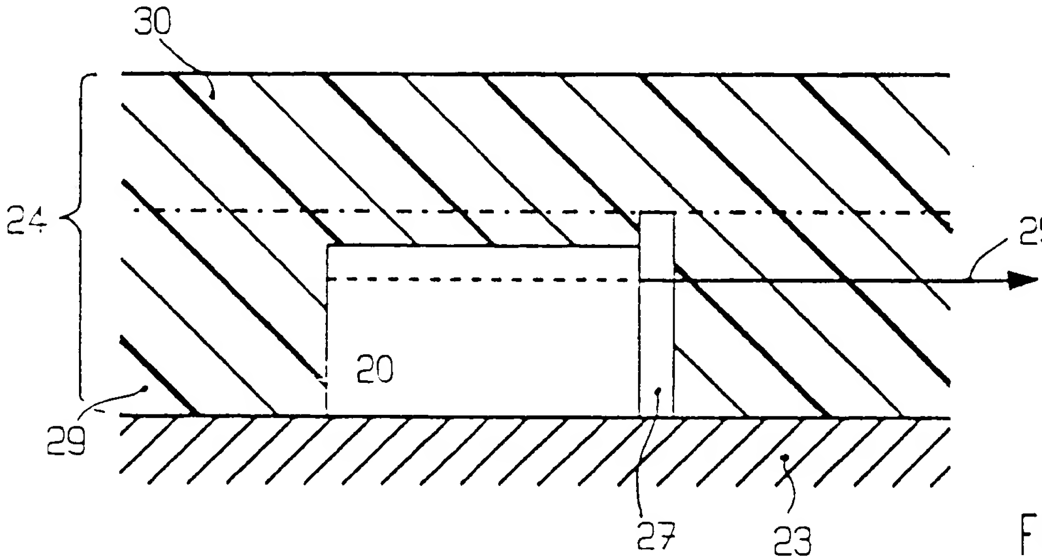

FIG. 3C

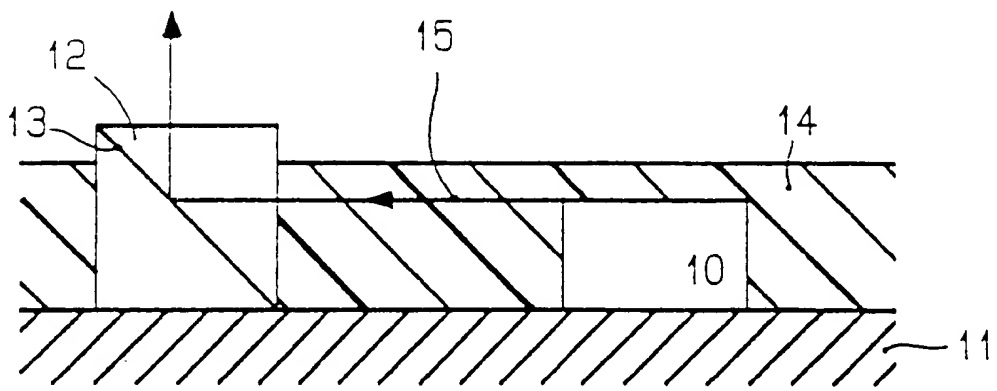

FIG. 1

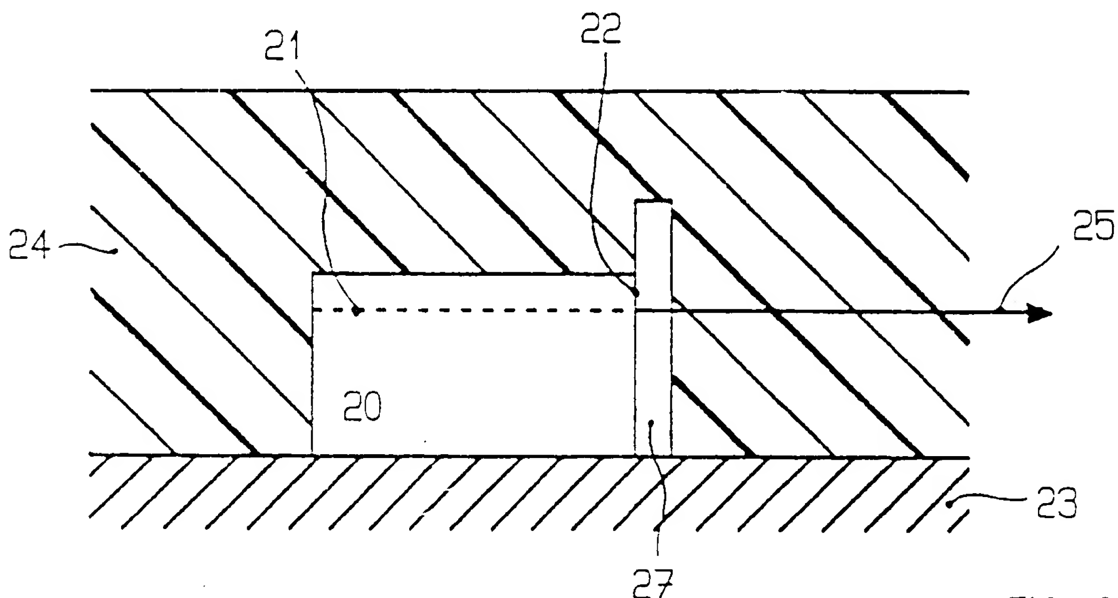

FIG. 2